U.S. DEPARTMENT OF ENERGY

OCRWM

YUCCA MOUNTAIN

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT

WHAT WAS LEARNED FROM THE SNL AND M&O CONTRIBUTIONS TO TSPA 1993

PRESENTED TO

DOE-NRC TECHNICAL EXCHANGE

PRESENTED BY

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DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA

SEPTEMBER 27-28, 1994
ROCKVILLE, MARYLAND

Outline

- Use of two approaches (SNL & M&O)
- Thermal loading
- Mode of emplacement and design alternatives
- General compliance
- Dose versus Complementary Cumulative Distribution Function (CCDF)
- Performance period
- Conclusions

Use of Two Approaches

Approach to Dual Participation in TSPA-93

- To ensure that needless differences in the two analyses would be avoided, the M&O would use the results of extensive SNL data-gathering

- The M&O would use the Repository Integration Program (RIP) code developed by Golder Associates, SNL would use its Total System Analyzer (TSA) code system

- The structure of the RIP code, as compared with TSA, dictated some differences in the use and encoding of data and in analytical approach

Contrasts in Approach for TSA and RIP

- Even when the two codes used the same conceptual approach, implementation differed in details

- Implementation contrasts included differences in:
  - The approach to the one-dimensional approximation of unsaturated flow and transport
  - The composite-porosity conceptual model
  - Infiltration/flux distributions and climate change
  - Saturated zone flow and transport
  - Radionuclide solubilities and distribution coefficients
  - Waste package corrosion and near-field characteristics

Meaning of SNL and M&O Modeling Differences

- For the closest comparable cases (see following two viewgraphs) there were no differences in results that would have been meaningful from a compliance-calculation perspective

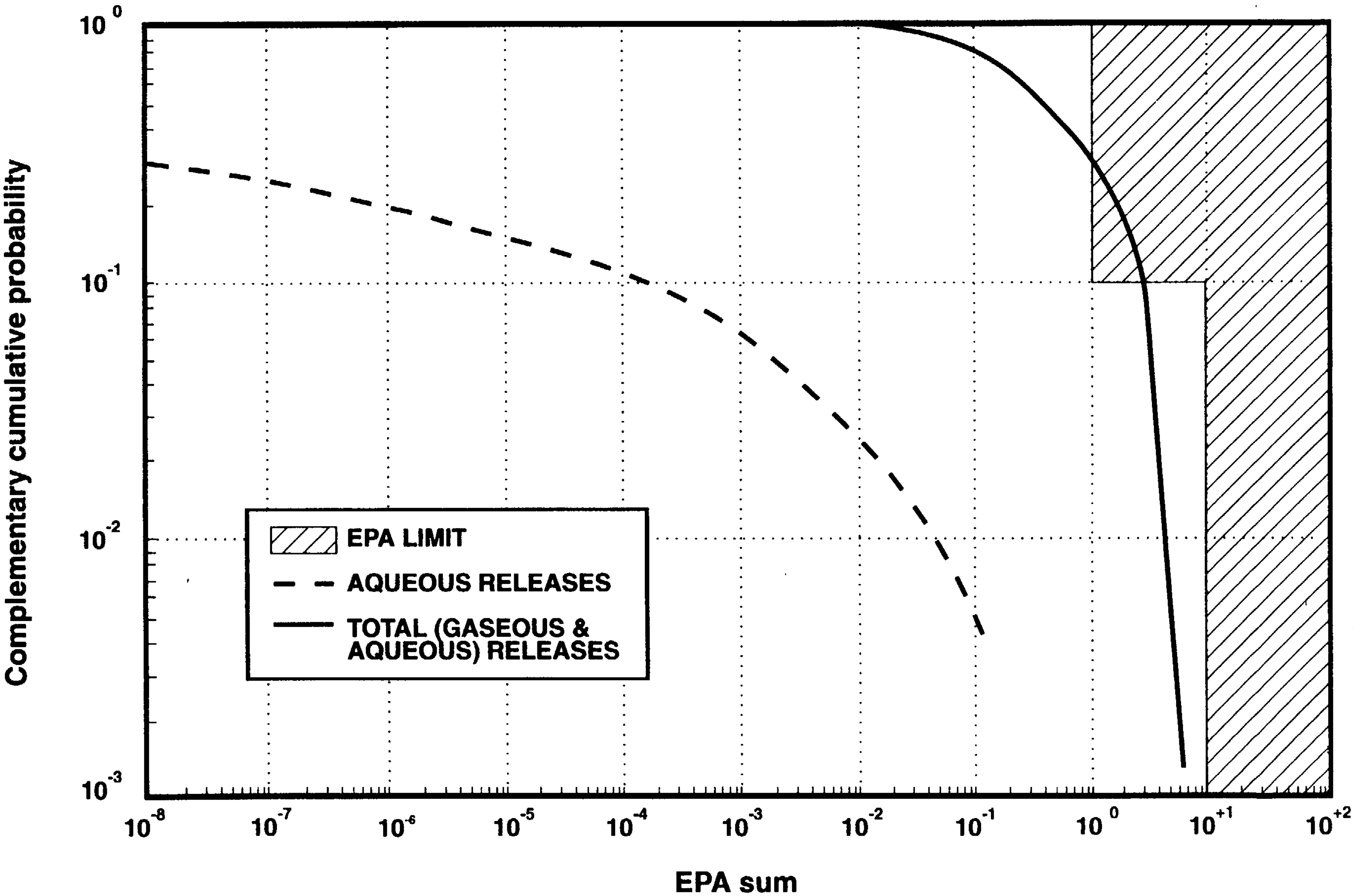
- Given these generally comparable results, it seems prudent that the performance assessment program now direct resources to

  - Evaluate the appropriateness of the conceptual model of unsaturated flow in view of alternatives

  - Link its modeling more directly to the results coming from the site program, especially its 3-D site-modeling effort

Schematic of SNL CCDFs of Normalized Cumulative Release over 10,000 Years for Nominal Aqueous and Total Releases

(57 kW/Ac; vertical emplacement, composite porosity model)

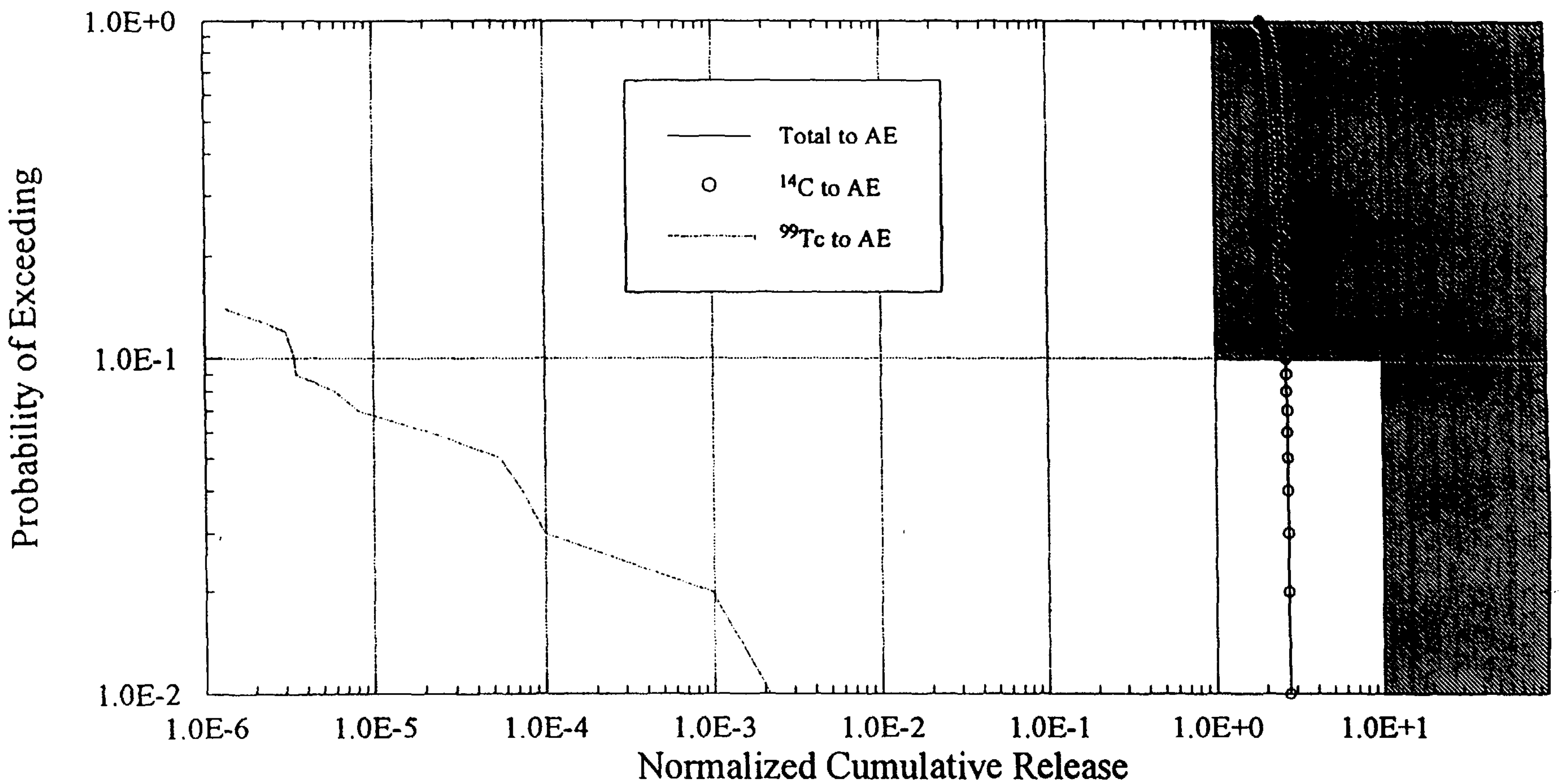


IRSNLMO2.CDR.125.NWTRB/1-12-94

no weeps

M&O CCDFs for Normalized Cumulative Releases over 10,000 years for Nominal Aqueous and Gaseous Releases

(57kW/acre, 10 cm outer and 0.95 cm inner containers, horizontal emplacement, composite porosity approximation)



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Thermal Loading

Thermal Loadings Evaluated

- M&O analyses were conducted to represent three thermal loads
  - 70.4 kW/ha (28.5 kW/acre)
  - 141 kW/ha (57 kW/acre)
  - 282 kW/ha (114 kW/acre)
- SNL analyses evaluated
  - 141 kW/ha (57 kW/acre)
  - 282 kW/ha (114 kW/acre)

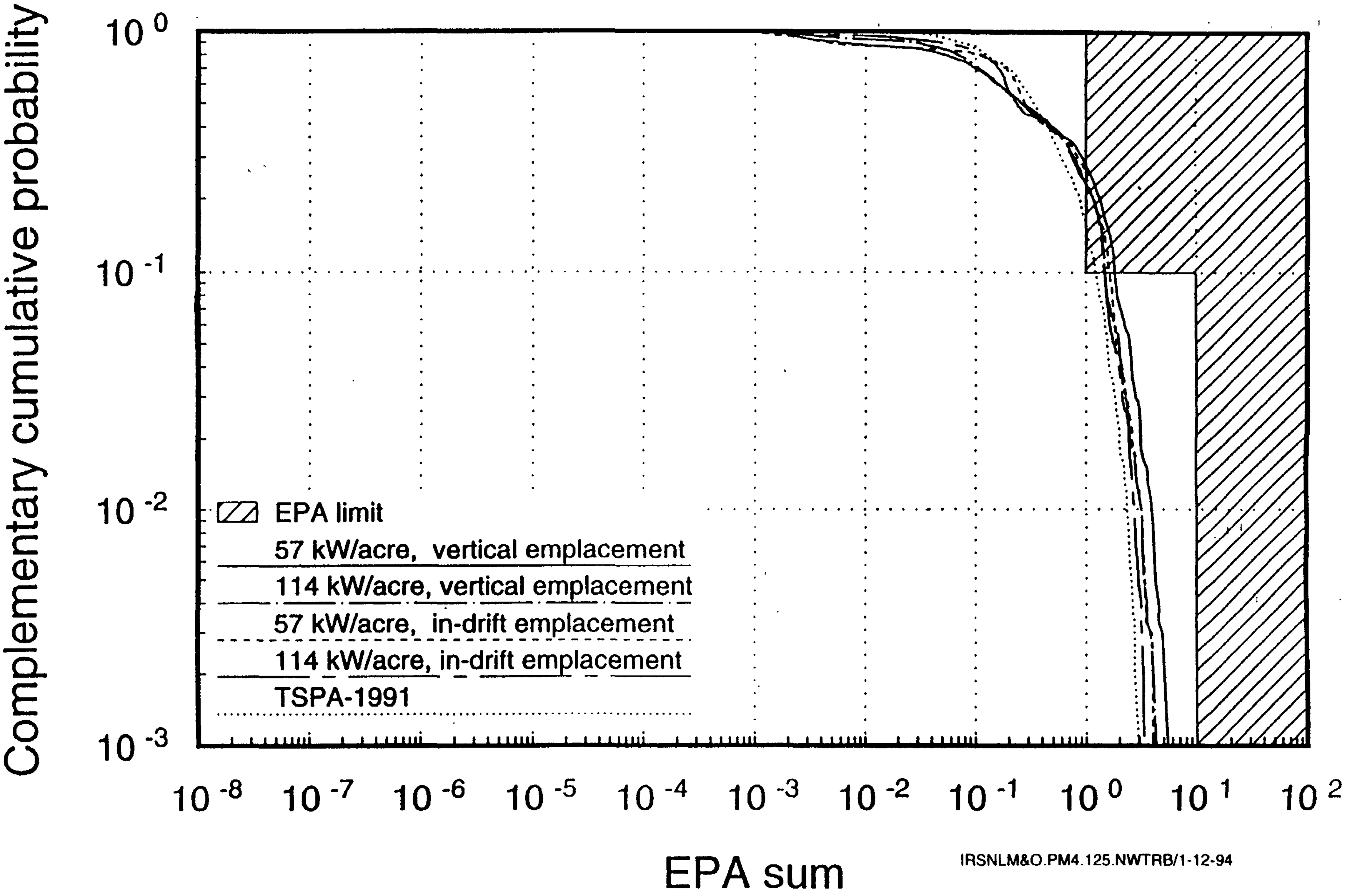
Alternative Designs Investigated in TSPA-93

	Alternative Thermal Loads (kW/Ac)		
	28	57	114
Vertical emplacement SCP design alloy 825 @ 0.95 cm		✓	✓
In-drift emplacement MPC mild carbon steel @ 10, 20, or 45 cm alloy 825 @ 0.95 cm and 3.5 cm	✓	✓	✓

Thermal Loading Results

- There was little difference between the 57 kW/acre and 114 kW/acre cases for the 10,000-year CCDFs in the SNL analyses
- In the M&O analyses, the 28 kW/acre case seemed to give the best performance result, followed closely by the 114 kW/acre case
- The apparent differences in performance attributable to thermal loadings directly reflect how much time waste packages spend in the temperature range of 80-100°C, the temperature range, where corrosion rates are highest
- Corrosion models used were based on a limited experimental record and expert judgement: work is needed to provide more definitive corrosion models for engineered system materials

CCDFs of Nominal Cumulative Release (Aqueous and Gaseous) Over 10,000 years for the Four Cases and for TSPA-91



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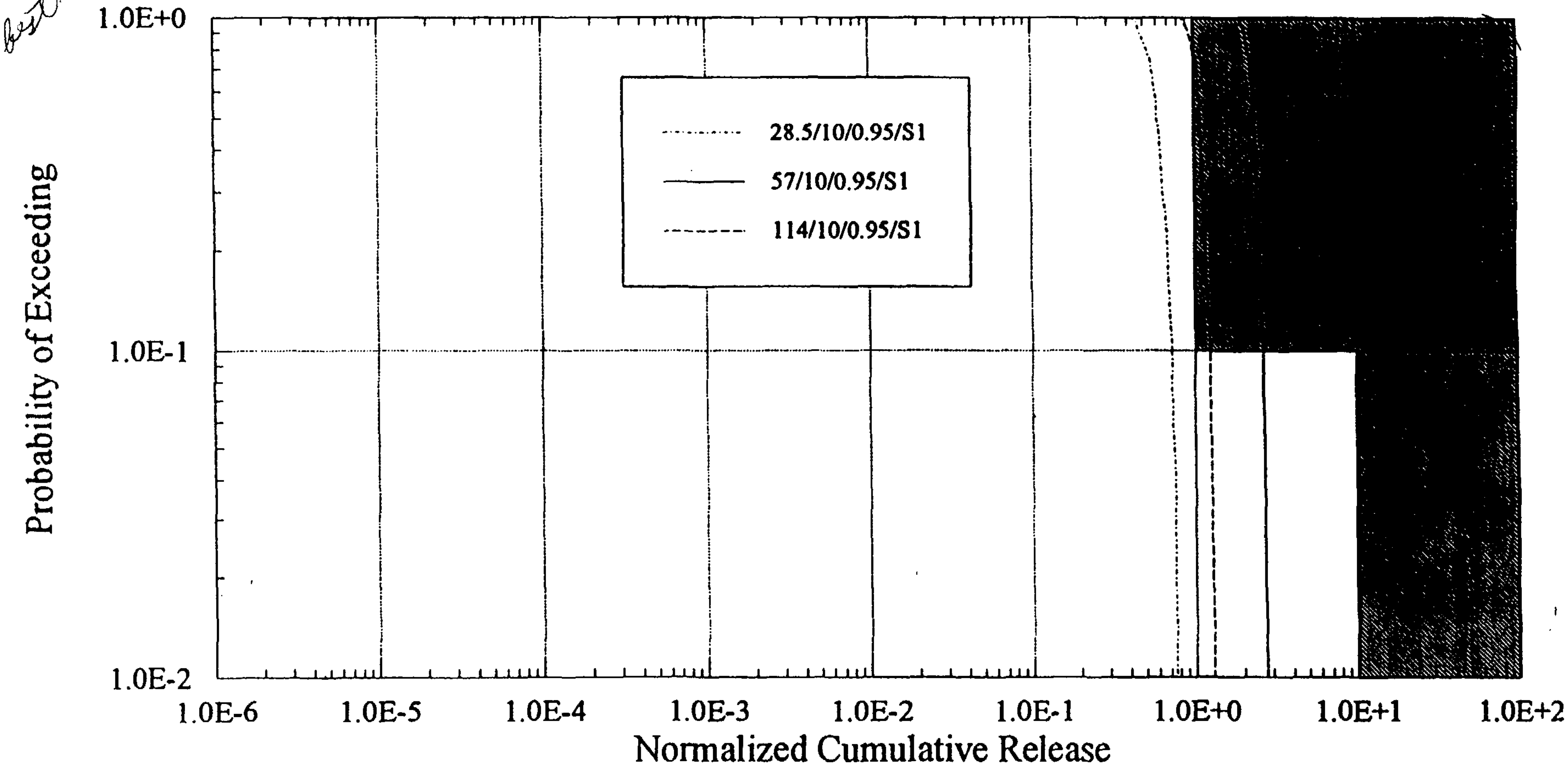
application of questionable corrosion rate model key to 28 kW/acre as best releases

Thermal Loading--100 Realizations at 10,000 Years: CCDF of Releases to the AE at 10,000 Years



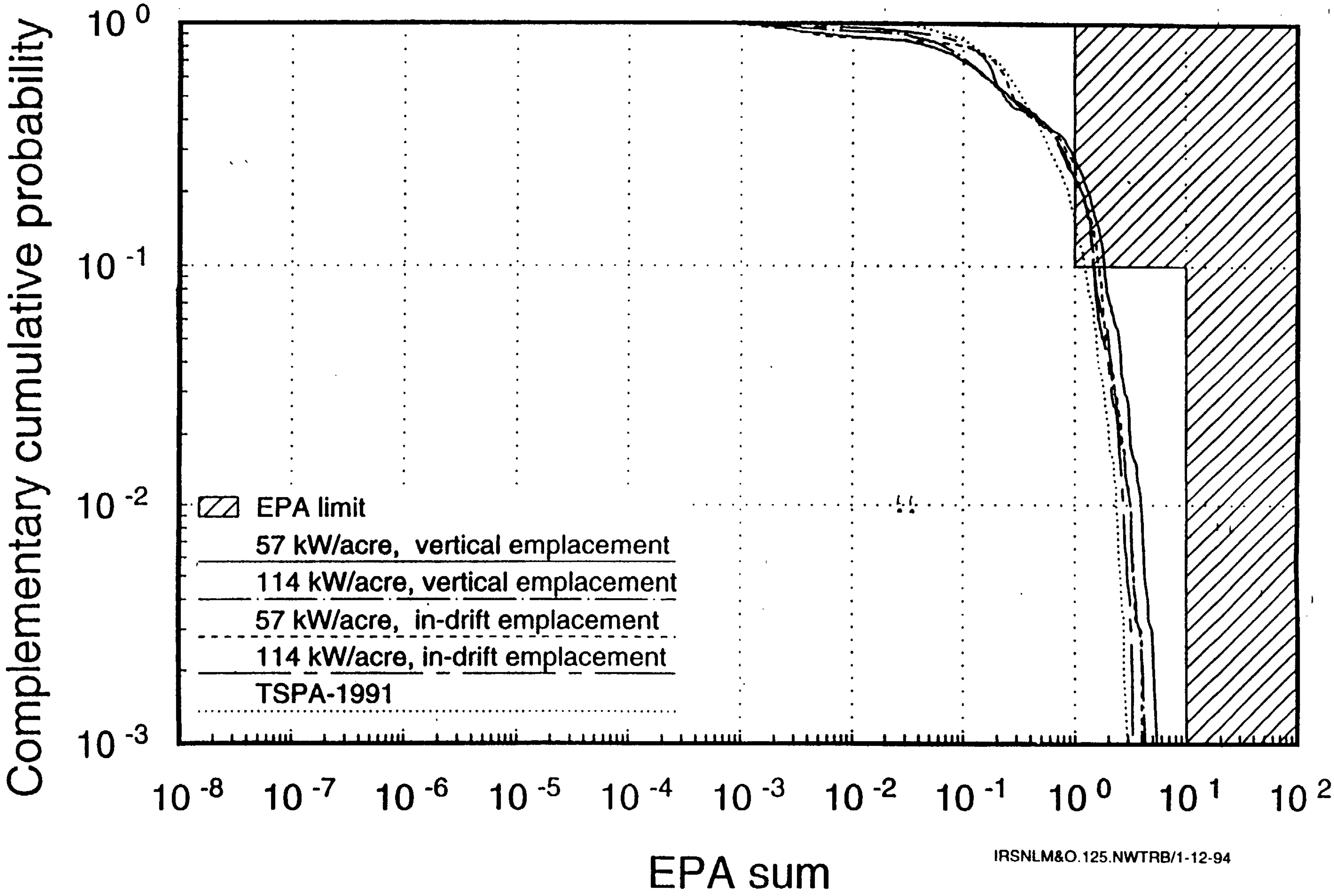
Mode of Emplacement and Design Alternatives

Emplacement Mode

- Only SNL evaluated emplacement mode, results were non-significant differences in 10,000-year analyses for the nominal case

- For the human intrusion scenario analyses, the borehole case performed slightly better simply because of the lesser horizontal area that a vertical package represents as compared with the same package laid horizontally

CCDFs of Nominal Cumulative Release (Aqueous and Gaseous) Over 10,000 Years for the Four Cases and for TSPA-91



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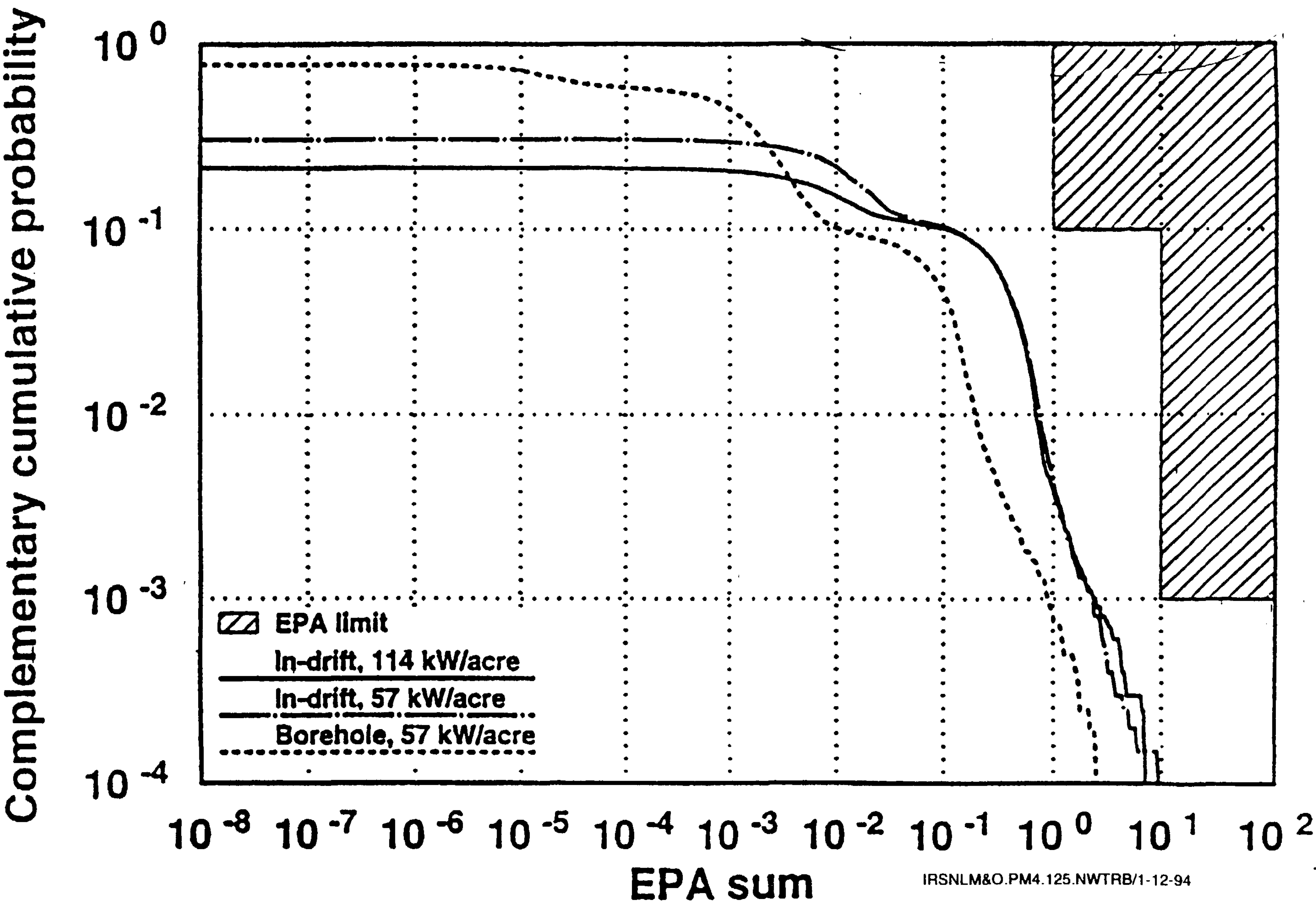
CCDFs of Nominal Cumulative Release for Human Intrusion Scenarios, 10,000 Years



Waste Package Design Variations

- M&O addressed the following designs for spent fuel waste packages:
  - Three outer corrosion-allowance material thicknesses
  - Two inner corrosion-resistant material thicknesses

- SNL analyses evaluated the following spent fuel waste packages:
  - Two sizes
  - Two outer-container wall thicknesses

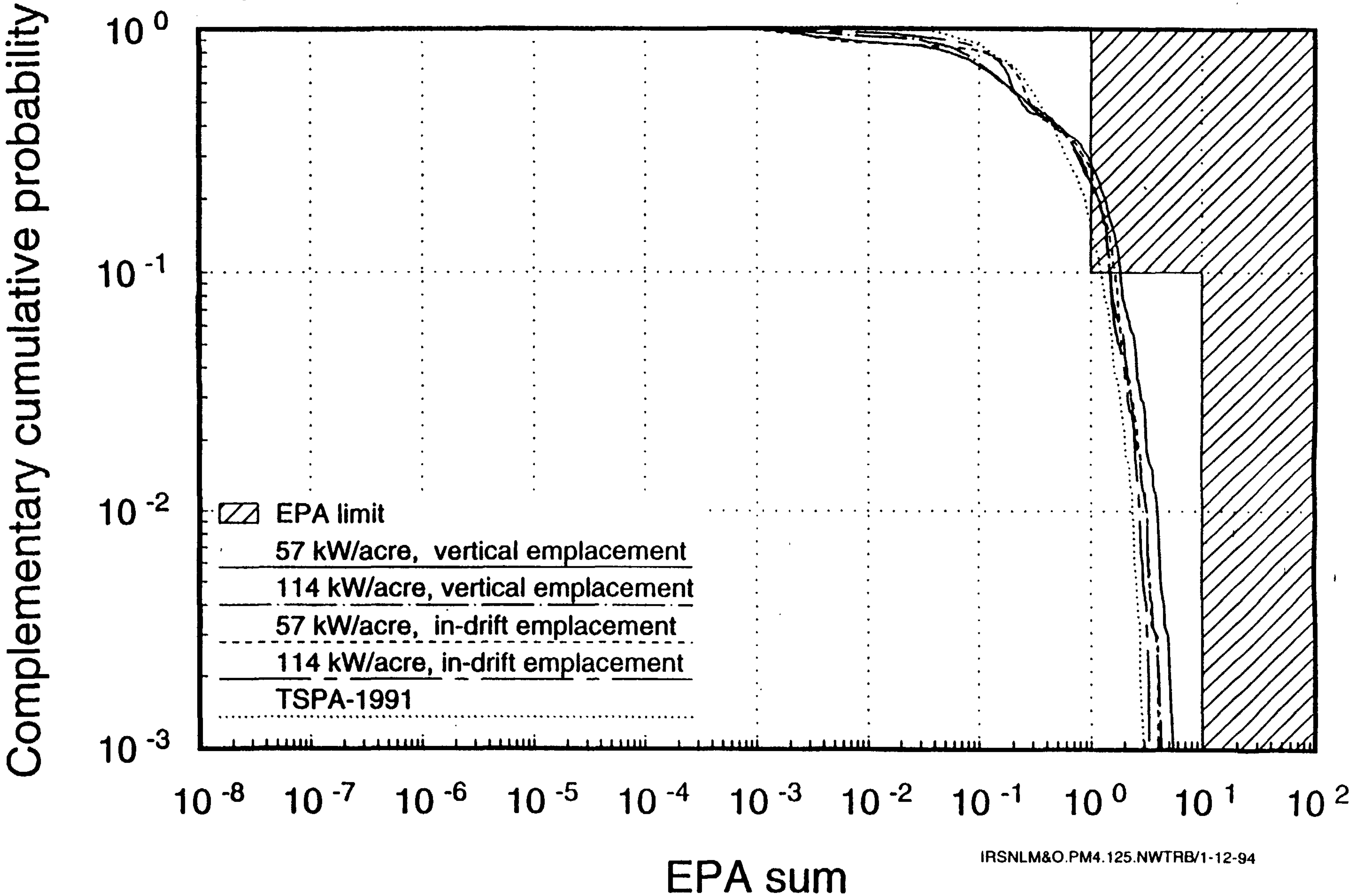
Alternative Designs Investigated in TSPA-93

	Alternative Thermal Loads (kW/Ac)		
	28	57	114
Vertical emplacement SCP design alloy 825 @ 0.95 cm		✓	✓
In-drift emplacement MPC mild carbon steel @ 10, 20 or 45 cm alloy 825 @ 0.95 cm and 3.5 cm	✓	✓	✓

Waste Package Design

- In terms of design, the SNL emplacement mode determined whether or not the waste package was 0.95 cm alloy 825 (borehole) or had an additional 10 cm overpack (in-drift)
  - Although there were differences in cumulative waste-package failure distributions, these differences were not significant in terms of 10,000-year cumulative releases
- M&O analyses addressed additional overpack thicknesses of 20 and 45 cm, and for the 10 cm case, a thicker inner barrier (3.5 cm)
  - Only the 45 cm mild steel overpack had a significant impact on performance up to 100,000 years

CCDFs of Nominal Cumulative Release (Aqueous and Gaseous) Over 10,000 Years for the Four Cases and for TSPA-91



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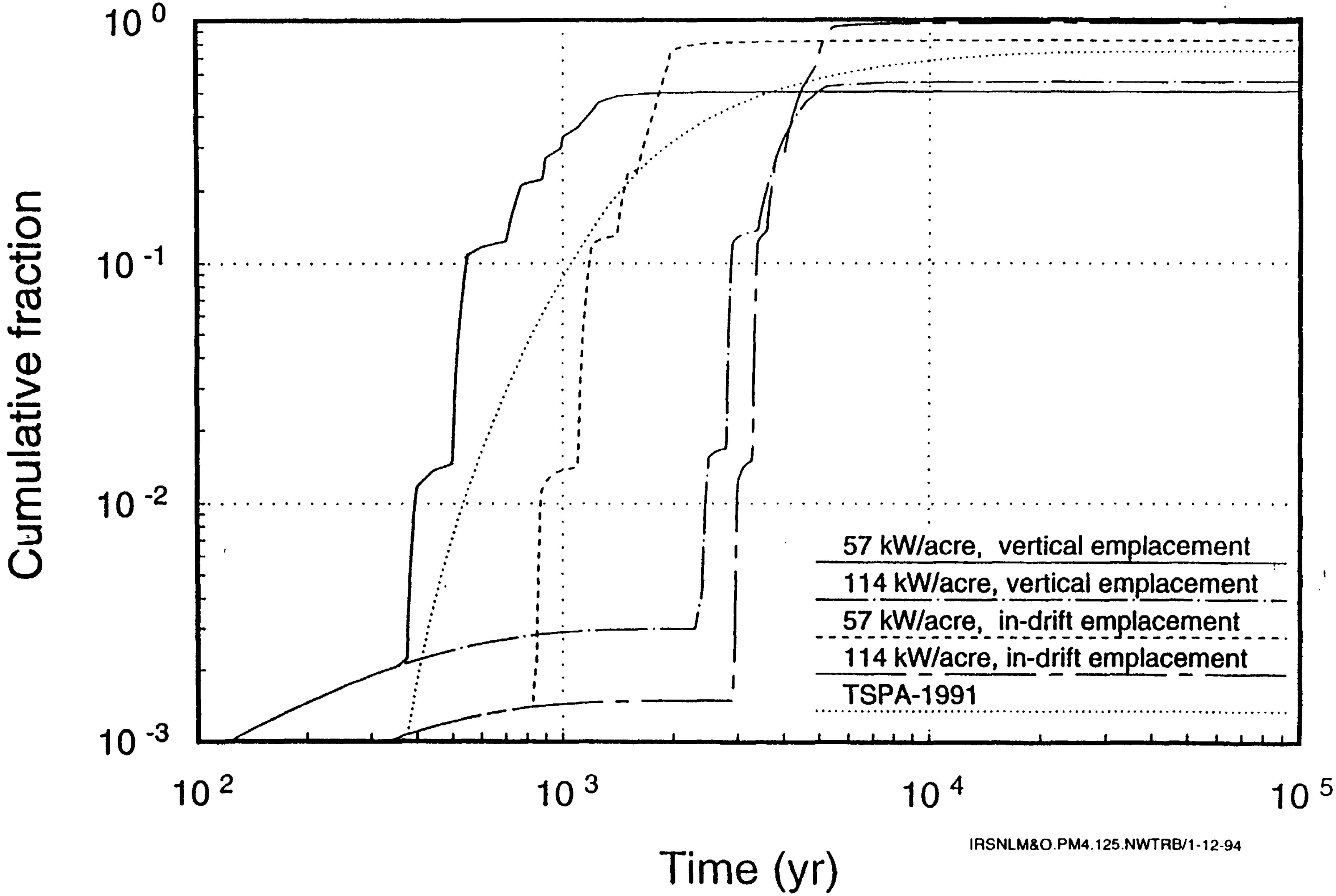
Distribution of Container-Failure Time for the Four Cases and for TSPA-91



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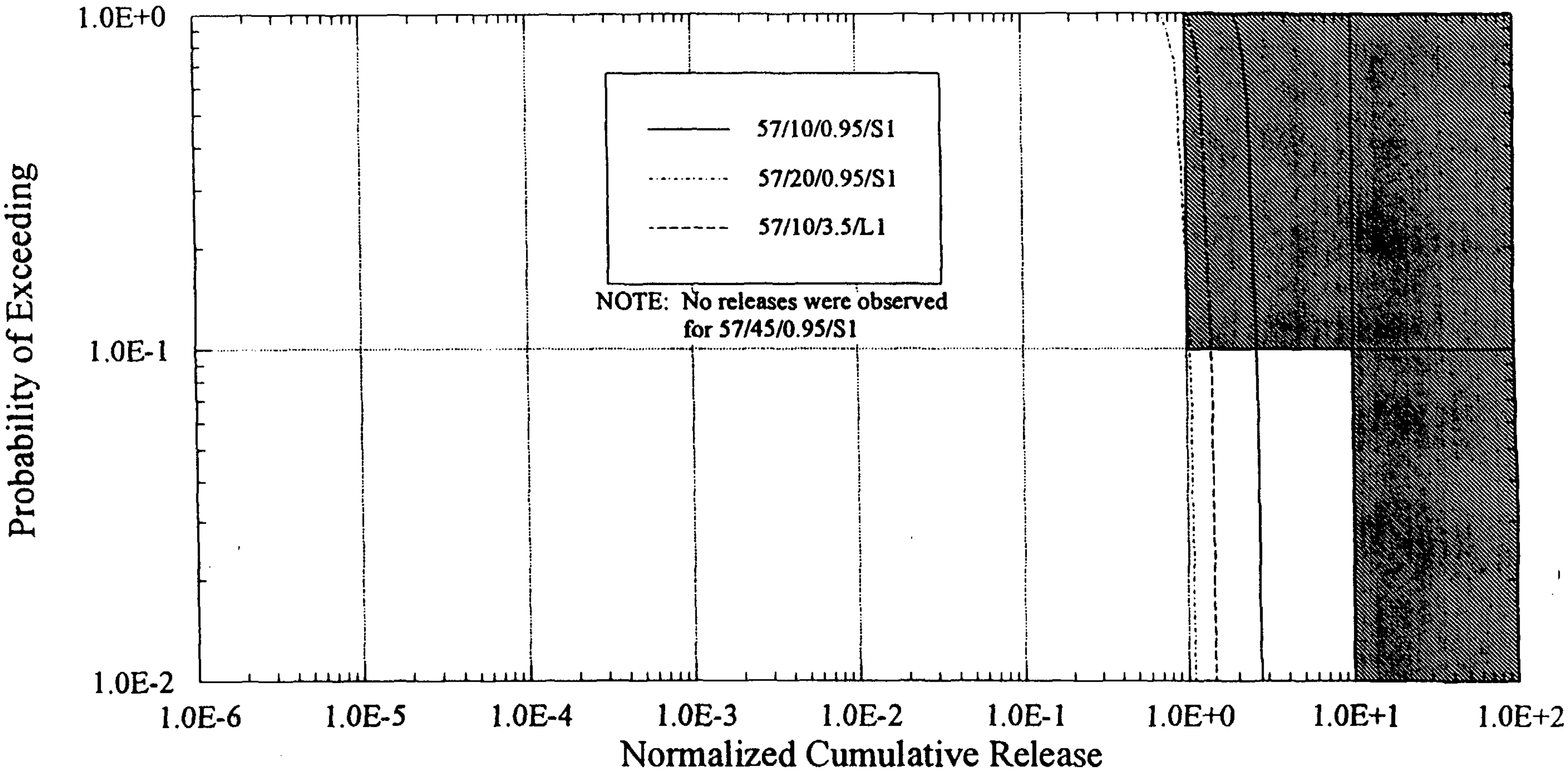
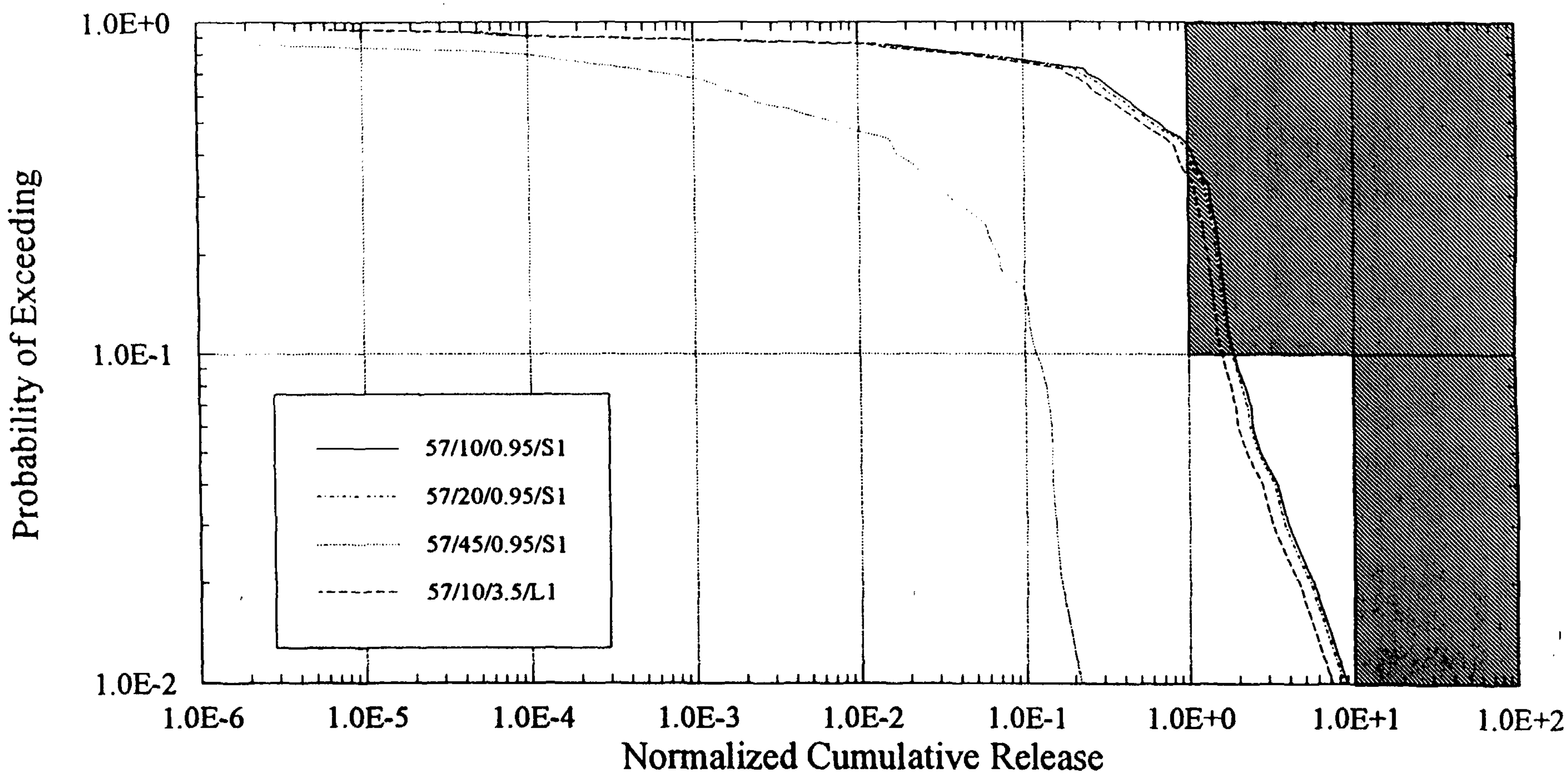
Container Thickness--100 Realizations at 10,000 Years:
CCDF of Releases to the AE at 10,000 Years



Container Thickness--100 Realizations at 100,000 Years:
CCDF of Releases to the AE at 100,000 Years



General Compliance

Compliance with 40 CFR Part 191 and 10 CFR Part 60

- The Environmental Protection Agency's general environmental standard (not currently applicable to Yucca Mountain)
  - Aqueous releases generally were orders of magnitude below performance goals
  - Gaseous releases of C-14 generally violated performance goals
- The Nuclear Regulatory Commission's 10 CFR 60.112 engineered barrier system requirements were not evaluated

Dose versus Complementary Cumulative Distribution Function (CCDF)

Significance of Parameters for Release and Dose Results

- Key site issue is conceptual model for flow and transport through fractured-porous media and the magnitude of unsaturated zone percolation flux
- Most analyses of the hydrologic flow regime in the unsaturated zone (whether ambient or thermally perturbed) assume composite porosity flow model
- Validity of this assumption and its impact on predicted performance should be more rigorously evaluated

Significance of Parameters for Release and Dose Results

(Continued)

- The representation of the possible increase in flux that may be attributable to future climate changes is uncertain and important to either result
- Secondary effects of climate change: increased saturated zone flux and mixing depth are important to dose
- Doses from gaseous release of C-14 to accessible environment not evaluated

Saturated Zone is of Particular Significance to Dose Results

- **Aqueous release to accessible environment relatively insensitive to flow in the saturated zone**
  - Unsaturated zone travel-time long compared to saturated zone travel-time
- **Doses from aqueous releases at the accessible environment directly related to the flux through the saturated zone**
  - If a dose-based standard is promulgated, a greater understanding of the saturated zone will be required

Biosphere Modeling Necessary for Definitive Dose Calculations

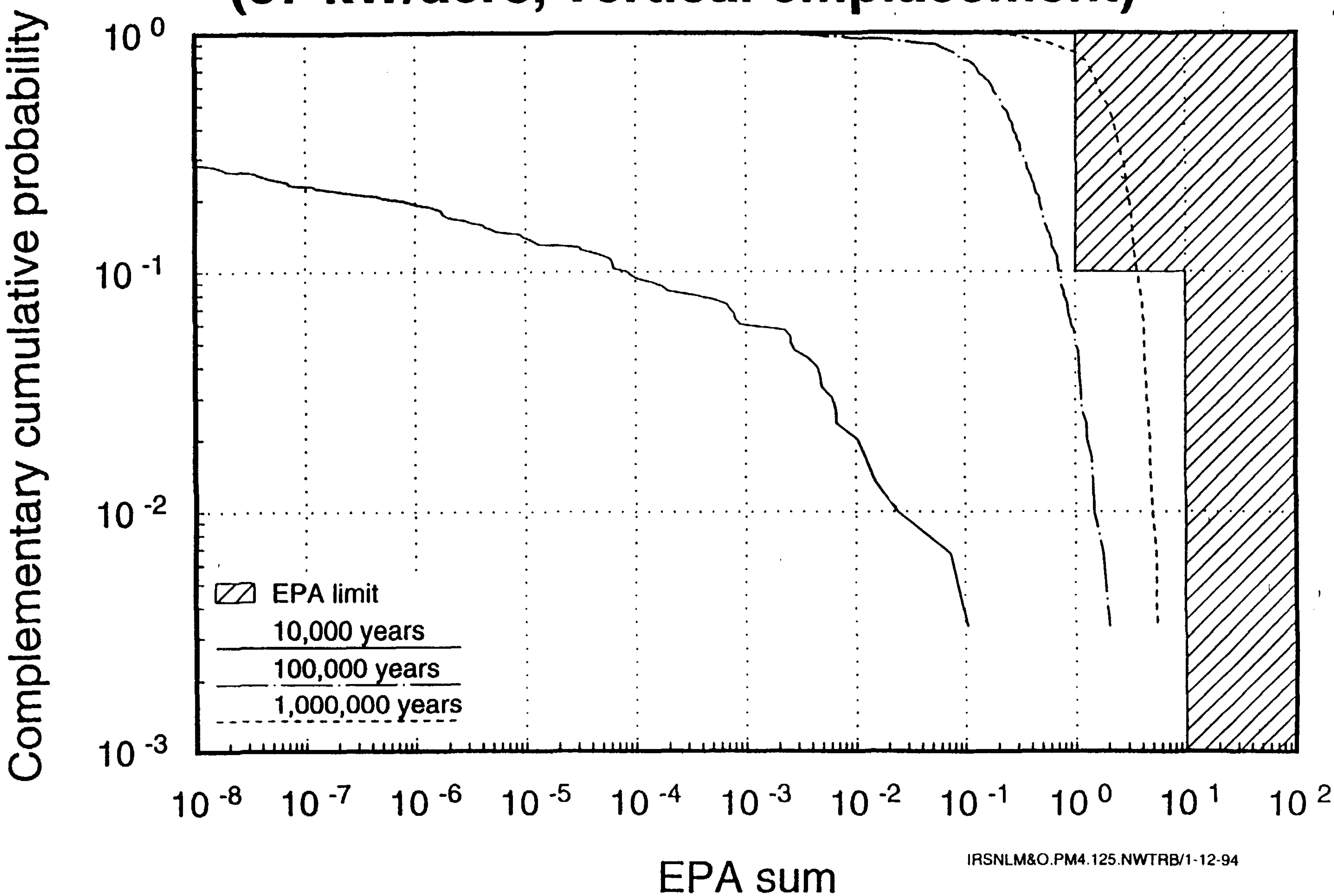
- Biosphere modeling needs to address climate change and human development
- Reference biospheres specific to Yucca Mountain, over time, would be needed
- A comprehensive list of features, events, and processes (FEPs) of relevance for biosphere modeling would need to be developed
- Defensible method must be used for screening and combining FEPs into biosphere models
- There may be greater uncertainty in long-term biosphere modeling than in geosphere modeling

Performance Period

Reasons for Conducting Analyses Over Time-Periods Greater than 10,000 Years

- Evaluate consequences associated with long-lived radionuclides not released in 10,000 years
- Provide "better insight on the long-term performance of disposal alternatives"
- Compare results with other countries that consider dose over longer time-periods
- Prepare for discussions with the National Academy of Sciences Committee on Technical Bases for Yucca Mountain

Distribution of Cumulative Aqueous Release (57 kW/acre, vertical emplacement)



When Considering the 10,000 Yr Time-Period

- Virtually all (greater than 99.99%) of the release to the accessible environment is the result of C-14

- Cumulative aqueous release to the accessible environment has about a 90% probability of being less than 10^{-6} of the EPA limit

- Aqueous releases are generally insignificant over 10,000 years, but are very sensitive to the percolation flux and the conceptual model for fracture-matrix interaction

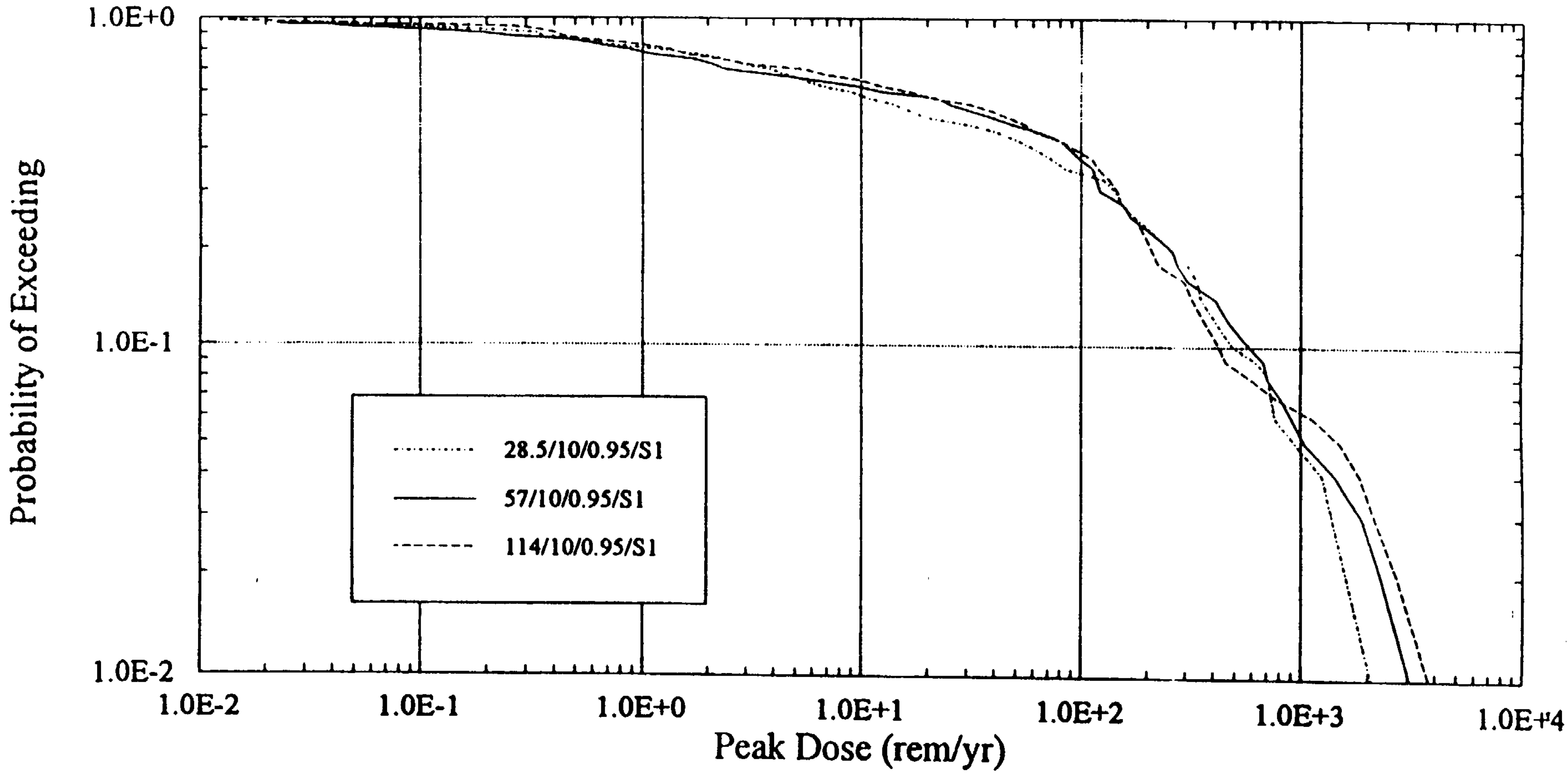
For the 100,000 Yr Time-Period

- Gaseous release accounts for half of total release
- Remainder is provided by unretarded aqueous species, primarily ^{99}Tc
- Generally, cumulative aqueous radionuclide release over 100,000 years is insensitive to the thermal load and outer barriers less than 20 cm
- Outer barriers on the order of 45 cm, especially when combined with low thermal loads, result in 100,000 yr waste packages

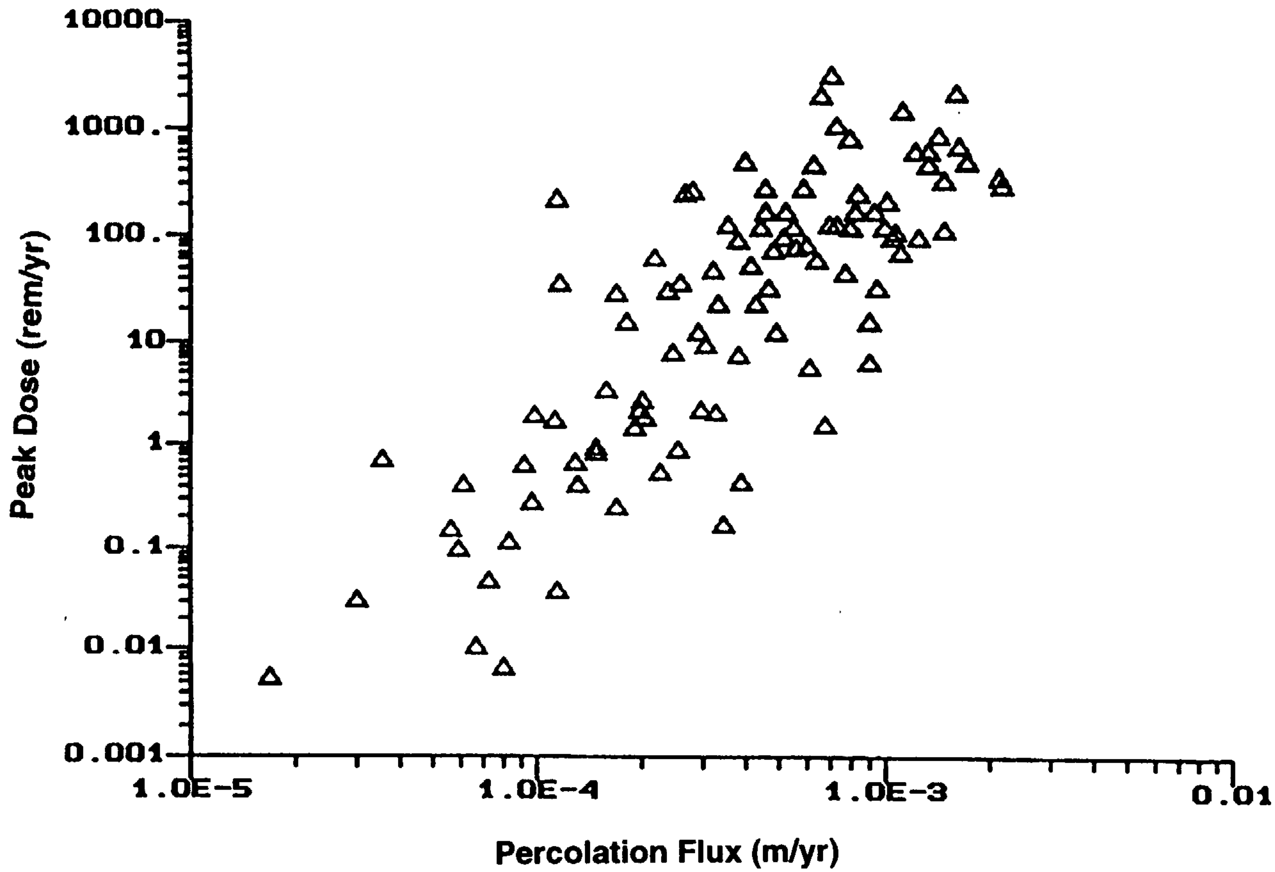
Doses Over the 1,000,000 Yr Time-Period

- Peak doses generally attributable to ^{237}Np
- Where this is not the case, either there is low flux through the unsaturated zone, high Np retardation, or low Np solubility
- Peak dose over 1,000,000 years is insensitive to thermal loads and waste package design
- Peak dose is sensitive to saturated-zone mixing depth
- Dose also sensitive to dose-conversion factors

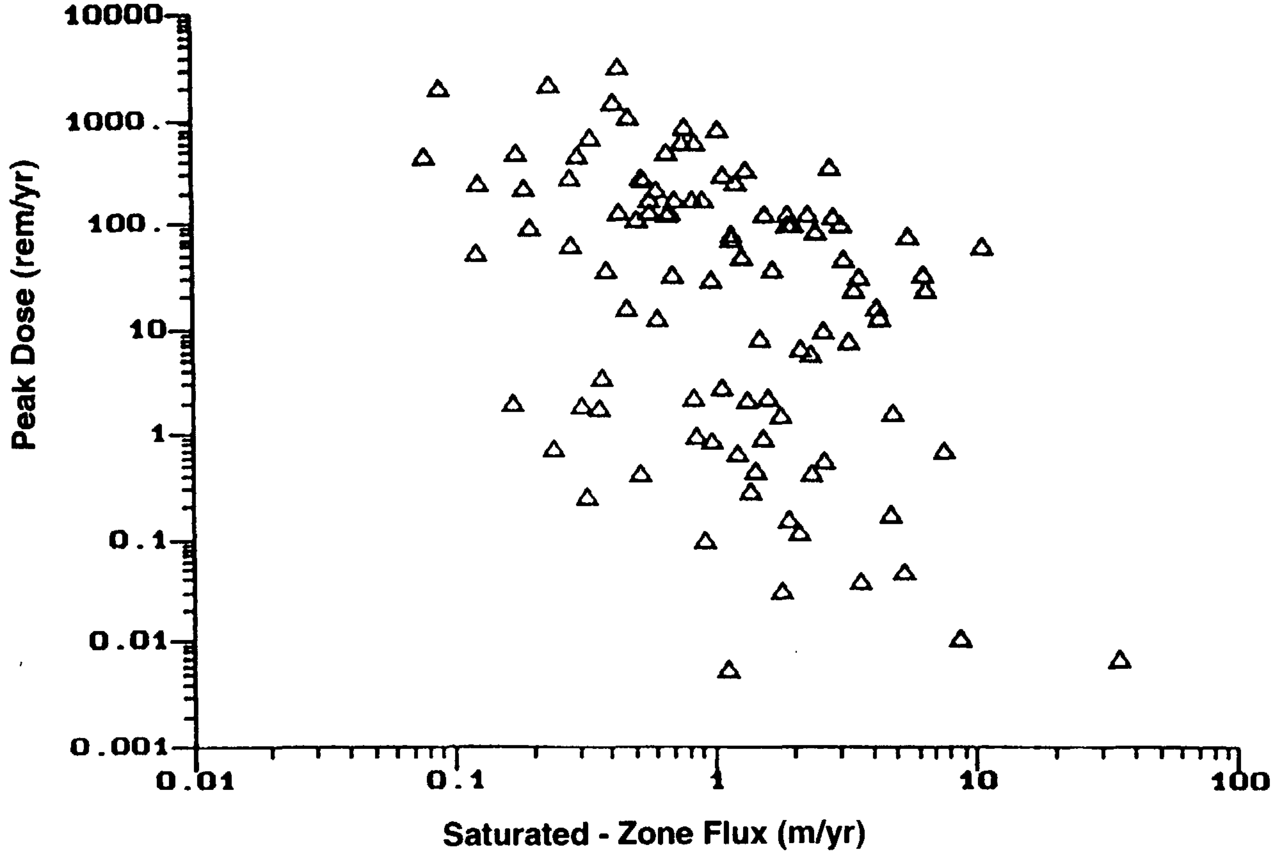
Peak Dose up to 1,000,000 Yrs: Alternative Thermal Loads



Sensitivity of Peak Dose to Percolation Flux



Sensitivity of Peak Dose to Saturated Zone Flux



CONCLUSIONS

Conclusions of Significance To Design

- Conclusions regarding relative advantages or disadvantages of a particular design are preliminary

- In general, when considering the integrated release from the waste package over 10,000 years, the 282 kW/ha (114 kW/acre) case generates lower releases than the 141 kW/ha (57 kW/acre) case

  - This reduction is primarily a result of the delay in the initiation of aqueous corrosion due to the higher thermal load

  - High level waste packages tend to fail earlier from redistribution of moisture, for system performance this is more than offset by the increased time to failure of the spent fuel waste packages

Conclusions of Significance To Design

(Continued)

- **Conclusions reached for the 10,000-year integrated release for different thermal loads are also germane to the 100,000-year time period**
  - Differences in release between the two higher thermal loads were less at this longer time period, suggesting they are not significant
  - The exception was the 45 cm outer barrier (unrealistic) where failure of waste packages was delayed for 40,000 to 60,000 years, and 100,000 year cumulative releases were well below those for thinner-walled overpacks
  - For 45 cm overpacks the 282 kW/ha (114 kW/acre) case produced an unexpected increase in 100,000-year cumulative release to the host rock: corrosion rates were accelerated during the longer period spent in the 70 to 100C temperature range

Conclusions of Significance To Design

(Continued)

- **A 70.4 kW/ha or 28.5 kW/acre thermal load resulted in lower releases from the waste package than the 141 kW/ha (57 kW/acre) case**
  - **This difference was pronounced for the 10,000-year integrated release, but was reduced to insignificance for the integrated release over 100,000 years**
  - **This improvement in performance is a direct result of the temperature dependence of the aqueous corrosion rate assumed in the modeling: less time spent in the 70-100C range**
- **Whether the preliminary corrosion models being used in these analyses are realistic remains to be determined**

Conclusions of Significance To Design

(Continued)

- Gaseous releases (i.e., ^{14}C) dominate cumulative 10,000-year releases, and releases to the accessible environment are a direct function of waste package lifetime because travel times to the accessible environment are short
- Thus, the 141 kW/ha (57 kW/acre) case yields greater ^{14}C releases than either the 282 kW/ha (114 kW/acre) or the 70.4 kW/ha (28.5 kW/acre) thermal load, assuming current conceptualizations of gas flow and corrosion
- This means that if the new standard applicable to Yucca Mountain retains current restrictions on the release of ^{14}C, thermal loading increases in importance

Conclusions of Significance To Design

(Continued)

- Integrated aqueous releases to the accessible environment over 10,000 years are extremely small, generally less than 10^{-6} of the EPA Table 1 values, and tend to reinforce the conclusion that very high and very low thermal loads yield lower releases than the moderate 141 kW/ha (57 kW/acre) thermal load
- When considering only aqueous releases over 100,000 years, cumulative releases decrease slightly as the thermal load is lowered, largely because of the increase in the alteration rate of spent nuclear fuel
- The effect of the thermal loading design on the peak individual dose over a 1,000,000-year time period is insignificant

Conclusions of Significance To Design

(Continued)

- The use of the 3.5-cm inner corrosion resistant barrier, rather than a 0.95 cm inner barrier makes a difference to postclosure performance over 10,000 years when a spatially variable pit growth rate is used, depending on thermal load

- When extending the time frame to 100,000 years, the improvement in performance afforded by the increased inner barrier thickness is approaching insignificance

- Waste package design has little impact on the peak individual dose over the 1,000,000 year time period

Conclusions of Significance To Site Characterization

- It was assumed, except in the case of the SNL "weeps" model, that transport through the unsaturated zone is dominated by the matrix, either because of the large capillary pressure differences between the fractures and matrix *or* matrix diffusion due to the concentration gradient between the fractures and matrix
- Most analyses of the hydrologic flow regime in the unsaturated zone have assumed the composite porosity flow model: this assumption needs evaluation
- Ambient percolation flux was considered to be uncertain, with uncertainty broken into two distributions
  - One representing the uncertainty in the current conditions
  - The other representing uncertainty due to future climates
  - These distributions need to be constrained by site observation, testing and process-level modeling

Conclusions of Significance To Site Characterization

(CONTINUED)

- Matrix properties (porosity, bulk density, retardation) govern radionuclide transport, but uncertainty was relatively insignificant over ranges evaluated
- Uncertainties in retardation coefficients of key radionuclides such as ^{237}Np play a potentially significant role for releases over the 100,000-year time frame
- Analyses of thermally perturbed gaseous flow and ^{14}C transport in the unsaturated zone as well as aqueous flow in the saturated zone were improved
  - Both models rely on the bulk permeability of fractured-porous media, underscoring the need for a comprehensive description of this parameter
  - Gaseous release to the accessible environment is relatively insensitive to the potential rate of gaseous flow in the unsaturated zone
  - Aqueous release to the accessible environment is relatively insensitive to the aqueous flow in the saturated zone, while dose is directly related to the horizontal flux through the saturated zone

Conclusions of Significance To Alternate Environmental Standards

- **When considering the 10,000-year time period**
  - Virtually all (greater than 99.99 percent) of the release to the accessible environment is the result of ^{14}C
  - The cumulative aqueous release to the accessible environment has about a 90 percent probability of being less than 10^{-6} of the EPA limit
- **When considering the 100,000-year time period**
  - Gaseous release accounts for over half of the total release to the accessible environment
  - The remainder is provided by unretarded aqueous species, primarily ^{99}Tc
  - For aqueous radionuclides that do reach the accessible environment in 100,000 years or less, the results are sensitive to the percolation flux

Conclusions of Significance To Alternate Environmental Standards

(CONTINUED)

- When considering the 1,000,000-year time period
  - Peak dose is attributable to ^{237}Np, exceptions are the result of either a very low percolation flux through the unsaturated zone, a very high retardation in the unsaturated zone, or a very low solubility
  - Peak dose is insensitive to thermal loads and waste package designs
  - Peak dose is very sensitive to the percolation flux, the Np solubility, and the assumed mixing depth in the saturated zone: site characteristics assumed to remain substantially unchanged over geologic time
  - Peak dose will also be sensitive to the assumed dose conversion factor, which has nothing to do with the site

- When considering the performance measure to be regulated, peak doses for 10,000 and 100,000 years were well correlated with cumulative releases to the accessible environment aqueous

not as fine for PA [illegible] sat zone mixing

Conclusions of Significance To Total System Performance Assessments

- The performance assessment program needs to have a set of models that can properly address the system and subsystem performance implications of both the data being obtained and the remaining uncertainties

- It is still necessary to evaluate the effects of:

  - Uncertain and spatially variable thermohydrologic properties

  - Uncertain fracture-matrix conceptual models

  - Uncertain ambient percolation fluxes on the expected far-field, near-field and waste-package thermal and hydrologic regimes as a function of time and space

  - Uncertainty regarding processes affecting the initiation and rate of aqueous corrosion of the mild steel outer barrier and the Alloy 825 inner barrier

Conclusions of Significance To Total System Performance Assessments

(CONTINUED)

- **Other aspects of the near-field thermohydrology are also uncertain**
  - Some near-field performance may involve coupled thermo-hydrologic-chemical effects: water removal by the spreading of the boiling isotherm, the potential for condensate flow back onto some of the waste packages, and the dynamics of rewetting as the thermal output wanes
    money, time focussed on near-field environment.
  - Uncertainty in engineered system performance is also affected by the uncertainty in the design, the waste stream, and the characteristics of a backfill, if one is to be used
  - The backfill question has importance to the modeling of waste package temperatures, but also potentially controls water contact mode and rate, and radionuclide transport mode and rate

Conclusions of Significance To Total System Performance Assessments

(CONTINUED)

- Conceptual understanding of how water moves through the unsaturated zone at Yucca Mountain should be improved
  - The potential role of continuous localized fracture flow, as considered in the Weeps model, or of episodic fracture flow, should be evaluated
  - Additional testing is required to determine the correct conceptual model or models for unsaturated flow
- Ambient unsaturated zone flux remains a very significant parameter
  - Any direct or indirect observations to better quantify the expected value and its uncertainty should be used
  - Likely thermal perturbation of the ambient hydrologic system needs to be evaluated, as do the potential changes in flow system characteristics from climate change, seismic, tectonic and volcanic activity

Conclusions of Significance To Total System Performance Assessments

(CONTINUED)

- In addition to the conceptual understanding of flow, there is a need to evaluate the representation of radionuclide transport through the unsaturated zone
  - The simplified K_d approach has been used to approximate the complex physical-chemical processes affecting transport of dissolved species
  - This approximation, as well as the parameter ranges used, need to be justified by detailed laboratory and field tests

Conclusions of Significance To Total System Performance Assessments

(CONTINUED)

- In terms of gas flow modeling, if the new standard for Yucca Mountains retains the current restrictions on the release of ^{14}C, improvements are needed in both site understanding and modeling approach
  - Analyses of gaseous and aqueous transport need to be linked through the use of the same data and common geometric descriptions of the system
  - Gas transport time distributions are needed to match the thermal loading cases being modeled
  - Further site data on gas permeabilities, perhaps as a function of water saturation, are needed to determine gas transport parameters

An Overall Conclusion From TSPA-1993

- It is relatively straightforward to abstract results from more detailed, deterministic process-level models for use in simplified, probabilistic system-level models
- What is now required is more complete sensitivity and uncertainty analyses, using the detailed process-level models to verify that the system-level models correctly represent the important processes